



Assessing Sonar Performance in Realistic Environments

11ch Applied Research Project Final Report

Sean P. Pecknold

Defence R&D Canada – Atlantic

Technical Report

DRDC Atlantic TR 2012-114

October 2012

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Abstract

The Assessing Sonar Performance in Realistic Environments (ASPIRE) project, completed in March 2012, was a four year Applied Research Project that was intended to determine how to sample the underwater environment in an adaptive and optimal manner to enhance tactical decision making for anti-submarine warfare (ASW). The project achieved its proposed outcomes, developing and improving tools for identifying what aspects of the environment limit our ability to accurately predict sonar performance, and how to best sample the environment to minimize these limitations. The project also demonstrated our capability for using Rapid Environmental Assessment (REA) techniques to optimize our predictions and sonar performance, and showed how REA-derived products and predictions can be integrated with the ASW tactical picture.

Résumé

Le projet de recherches appliquées ASPIRE (Assessing Sonar Performance in Realistic Environments – Évaluation du rendement des sonars dans des environnements réalistes) a duré quatre ans et a pris fin en mars 2012 ; il visait à déterminer comment échantillonner l'environnement sous-marin de manière adaptée et optimale afin d'améliorer la capacité de prise de décisions tactiques liées à la lutte anti-sous-marine (LASM). On a obtenu les résultats proposés dans le cadre de ce projet, soit mettre au point et améliorer des outils d'identification des aspects de l'environnement qui restreignent notre capacité à prédire avec précision le rendement des sonars, ainsi que déterminer la meilleure méthode d'échantillonnage de l'environnement en vue de réduire au minimum ces restrictions. Le projet ASPIRE a également permis de mettre de l'avant notre capacité d'utilisation des techniques d'analyse environnementale rapide, afin d'optimiser nos prédictions et le rendement des sonars. De plus, on a pu démontrer comment intégrer les produits dérivés d'analyse environnementale rapide et les prédictions à la situation tactique de LASM.

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Executive summary

Assessing Sonar Performance in Realistic Environments

Sean P. Pecknold; DRDC Atlantic TR 2012-114; Defence Research and Development Canada – Atlantic; October 2012.

Background: ASPIRE (Assessing Sonar Performance in Realistic Environments) was a four-year Applied Research Project (ARP), completed in March 2012. The objective of the project was to determine how to sample the underwater environment in an adaptive and optimal manner to enhance tactical decision making for anti-submarine warfare (ASW). Project components included collecting environmental data using Rapid Environmental Assessment (REA) techniques, numerical modelling of underwater acoustic propagation including the effects of environmental uncertainty and variability, and integration of sonar performance predictions into an ASW tactical picture to enhance decision making.

Principal results: During the course of the project, the anticipated outcomes were achieved. The capability to collect, exchange, and use the environmental data obtained via REA techniques, from Category I (historical) through to Category IV (in situ), was demonstrated. A capacity to integrate sonar performance predictions with an ASW tactical picture was evolved using the Environmental Model Manager (EMM). These predictions were based on realistic environmental parameters. A software tool was developed to identify what environmental uncertainties limited sonar performance capabilities, and to what degree. The potential for deriving environmental products for ASW from satellite imagery, in particular for ambient noise measurements, was also demonstrated.

Significance of results: This project has improved our capability to collect environmental data for ASW, particularly in a covert manner before entry into an operational theatre. The project has developed tools to optimize the sampling of environmental data by identifying the key parameters governing acoustic propagation and quantifying the uncertainty in sonar performance due to degraded or missing environmental information. It has improved the extent to which sonar performance predictions can be integrated with the ASW tactical picture thereby improving opportunities to exploit the environment to one's advantage or to be alert to vulnerabilities.

Future work: Future work will focus on two areas. The first is an extension of the performance prediction and optimal sampling work to handle different problems. These include identifying optimal and adaptive sampling strategies for active sonar, and in particular multistatic active sonar. The second is to apply the work on REA to the Canadian Arctic, to improve sonar performance prediction capabilities there and to determine to what extent

the problems of underwater sensing and communications will be affected by the changing environment. It is anticipated that this work will proceed under a new ARP on Performance Prediction for Underwater Sensing and Communications, as well as through support to the Advancing Multistatic Active Sonar Employment (AMASE) Technology Demonstration Project (TDP).

Sommaire

Assessing Sonar Performance in Realistic Environments

Sean P. Pecknold ; DRDC Atlantic TR 2012-114 ; Recherche et développement pour la défense Canada – Atlantique ; octobre 2012.

Contexte : Le projet de recherches appliquées ASPIRE (Assessing Sonar Performance in Realistic Environments – Évaluation du rendement des sonars dans des environnements réalistes) a duré quatre ans et a pris fin en mars 2012. L'objectif de ce projet était de déterminer comment échantillonner l'environnement sous-marin de manière adaptée et optimale afin d'améliorer la capacité de prise de décisions tactiques liées à la lutte anti-sous-marine (LASM). Les composantes de ce projet comprenaient la collecte de données environnementales à l'aide des techniques d'analyse environnementale rapide, la modélisation numérique de la propagation acoustique sous-marine (y compris les effets de l'incertitude et de la variabilité liées à l'environnement), ainsi que l'intégration des prédictions du rendement des sonars à la situation tactique de LASM, afin d'améliorer la capacité de prise de décisions.

Principaux résultats : On a obtenu les résultats anticipés au cours du projet. On a également démontré la capacité de collecte, d'échange et d'utilisation des données environnementales acquises au moyen de techniques d'analyse environnementale rapide, de la catégorie I (historique) à la catégorie IV (in situ). Une capacité d'intégration des prédictions de rendement des sonars à la situation tactique de LASM a été améliorée à l'aide du gestionnaire de modèles environnementaux (GME). Ces prédictions ont été fondées sur des paramètres environnementaux réalistes. Un outil logiciel a été mis au point afin de déterminer quelles étaient les incertitudes liées à l'environnement qui restreignaient le rendement des sonars, ainsi que leur degré d'incidence. On a également démontré le potentiel de dérivation des produits environnementaux pour la LASM à partir de l'imagerie satellitaire, en particulier en ce qui a trait à la mesure du bruit ambiant.

Importance des résultats : Le présent projet a permis d'améliorer notre capacité de collecte de données environnementales relatives à la LASM, en particulier de manière discrète avant l'entrée dans un théâtre opérationnel. Il a également permis de mettre au point des outils servant à optimiser l'échantillonnage des données environnementales au moyen de l'établissement des paramètres clés en matière de propagation acoustique, ainsi que de quantifier l'incertitude liée au rendement de sonars en raison de renseignements incomplets ou manquants relativement à l'environnement. On a pu améliorer le processus d'intégration des prédictions du rendement des sonars à la situation tactique de LASM, ce qui a multi-

plié les occasions d'exploitation de l'environnement à son propre avantage et nous a permis d'être plus attentifs aux vulnérabilités.

Perspectives : Les travaux futurs porteront principalement sur deux domaines. Le premier domaine est un prolongement des prédictions du rendement et de l'échantillonnage optimal en vue de gérer divers problèmes, y compris l'identification de stratégies d'échantillonnage optimales et adaptées pour des sonars actifs, en particulier des sonars actifs multistatistiques. Le deuxième domaine vise l'application des travaux sur des analyses environnementales rapides à l'Arctique canadien, afin d'améliorer les capacités de prédiction du rendement des sonars à cet endroit et de déterminer le degré d'incidence de l'évolution de l'environnement sur les problèmes liés à la détection et aux communications sous-marines. On prévoit que ces travaux seront réalisés dans le cadre d'un nouveau projet de recherches appliquées portant sur la prédiction du rendement en matière de détection et de communications sous-marines, ainsi que par le biais d'un appui au projet de démonstration technologique (PDT) pour l'avancement de l'utilisation du sonar actif multistatique.

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1 Background

The Assessing Sonar Performance in Realistic Environments (ASPIRE) Applied Research Project (ARP) began in April 2008 and was completed in March 2012. The project objective was to determine how to sample the underwater environment in an adaptive and optimal manner to enhance tactical decision-making for anti-submarine warfare (ASW). The basic approach of the project was to undertake battlespace characterization for ASW: from the collection of environmental data using Rapid Environmental Assessment (REA) techniques; through the exchange of data in the framework of a Recognized Environmental Picture (REP) and its input into numerical models for acoustic propagation; to the integration of sonar performance predictions into an ASW tactical picture to enhance decision-making.

1.1 Rapid Environmental Assessment

REA provides deployed forces with environmental information in littoral waters in tactical time frames [5]. REA is typically categorized by immediacy and ease of acquisition, where Category I REA is used to describe readily accessed, free environmental databases; Category II REA refers to more detailed, pre-cursor data, acquired in advance of deployment of forces; Category III REA is typically data obtained covertly; and Category IV REA refers to data collected *in situ*. During the first phases of REA, the focus is the initial assessment of a large area. For ASW, the assessment is specifically of detection requirements and capabilities.

1.2 Work Plan

In general terms, it is well-recognized that ASW in continental shelf waters is extremely challenging due to complex oceanographic conditions, numerous interactions with the bottom and surface boundaries, and the scales in time and space in which the conditions vary [6]. For example, quoting from this reference

“... survey requirements for bathymetry, bottom composition and beach characteristics for coastal naval operations are staggering. New satellite technology will help with some of the necessary data in the next several years, but large gaps will remain in our descriptive and predictive capabilities of the bottom as well as the capabilities of those oceanographic and acoustic models that are affected by the bottom.”

In response to these challenges, techniques and technologies for rapid environmental assessment of the continental shelf environment have been, and will need to continue to be, developed. The ASPIRE project was designed to go one step further by quantifying the impact of the environment on operations.

Based on the project approach, ASPIRE was organized into three work elements, capturing the main components of optimal sampling, data exchange and numerical models, and sonar performance prediction and decision making. The three work elements were designed to link sampling of the environment to the ASW tactical picture and back. The work breakdown elements (WBE) are described in Section 1.3.

1.3 Work Breakdown Elements

1.3.1 WBE 1: Optimal Sampling of the Underwater Environment

This WBE included both *in situ* and remote sensing techniques to characterize the underwater environment. *In situ* sampling was optimized by prioritizing the parameters to be measured, and the requisite spatial and temporal scales, by means of the parameter sensitivity functionality explored in WBE 2. The *in situ* sampling focussed on Category III and IV REA, that is covert (Cat. III) and overt (Cat. IV) sampling. The role of gliders and UUVs for Cat. III REA was explored. The remote sensing techniques focussed on Category II (pre-cursor) and III (covert) REA. RADARSAT imagery was used to estimate surface wind speed from which ambient noise could be estimated. This WBE was linked to other projects using RADARSAT and MODIS imagery that involved automating ocean feature analysis (such as fronts and eddies) as part of the Space-borne Ocean Intelligence Network (SOIN).

1.3.2 WBE 2: Environmental Model Manager+ (EMM+)

This WBE included numerical modelling of acoustic propagation and reverberation, and the exchange of environmental data. The acoustic modelling was used to predict passive and active sonar performance for WBE 3. It was also used to direct the optimal and adaptive sampling in WBE 1, by calculating the relative sensitivity of different environmental parameters governing acoustic propagation. Under this WBE, techniques were developed to flag (and potentially update) environmental parameters thought to be incorrect. Environmental data included static (typically Cat. I and II REA) and dynamic (typically Cat. III and IV REA) sources. Some environmental data was obtained from the sources identified in WBE 1, and some was obtained from external sources such as MetOc Halifax. This WBE was linked to broader DRDC and CF initiatives to develop a recognized environmental picture (REP), feeding into a recognized maritime picture (RMP), feeding into domain awareness (DW).

1.3.3 WBE 3: Sonar Performance Prediction Using Realistic Environments

Using realistic environmental data from WBEs 1 and 2, this WBE provided sonar performance predictions that were integrated with the ASW tactical picture. For ASW tactics,

the capability to display predictions of sonar performance along an operator specified radial track was demonstrated in the experimental sonar processing and tactical display system STB (the unclassified version of the PLEIADES system, which has been used in several sea trials on CFAV Quest and Halifax Class Frigates). This WBE also included marine mammal “zones of influence” calculations for operational CF active sources.

1.4 Military Fit

During the planning of the ASPIRE project, a number of shortcomings were identified in conjunction with RCN partners in the 1C (Underwater Warfare) Thrust. These were:

- There is limited capability to collect environmental data for ASW, particularly in a covert manner before entry into an operational theatre. (WBE 1)
- There is no capability to optimize the sampling of environmental data by identifying the key parameters governing the acoustic propagation or quantifying the uncertainty in sonar performance due to degraded or missing environmental information. (WBEs 1 and 2)
- There is limited capability to exchange marine environmental data within DND (as the recognized environmental picture is a notion, not a reality) and even less capability to exchange data between government departments. (WBE 2)
- Sonar performance predictions are not integrated with the ASW tactical picture thereby limiting opportunities to exploit the environment to one’s advantage or to be alert to vulnerabilities. (WBE 3)
- There is no capability to calculate zones of influence of operational sonars while at sea to mitigate harm to marine mammals. (WBE 3)

ASPIRE was intended to address these issues, by improving capabilities for the collection of environmental data for ASW; identifying key parameters for acoustic propagation and developing ways to quantify uncertainty in acoustic propagation based on uncertainty and variability in the environment; improving data exchange and storage capabilities through the REA database; integration of performance prediction with the ASW tactical picture using the EMM and System Test Bed; and providing a capacity for calculating marine mammal zones of influence.

1.5 Outputs and Deliverables

The outputs and deliverables of the ASPIRE project were designed to address the shortcomings described in Section 1.4. The key deliverables included:

1. Demonstration of the capability to collect, exchange, and use the environmental data obtained via Cat. I through IV REA techniques.
2. Demonstration of the capability to integrate sonar performance predictions with an ASW tactical picture.
3. Provision of sonar performance predictions that are based on realistic environmental parameters, for use in calculating zones of influence of naval sonars and for sonar simulations (e.g. multi-statics).
4. Evaluation of the potential to derive environmental products for ASW from MODIS and RADARSAT imagery.
5. Expert advice in the formulation of the statement of requirements for the Underwater Warfare Suite Upgrade/Canadian Surface Combatant.

1.6 Milestones

A set of milestones was developed for the ASPIRE project. The milestones were chosen to correspond to points in the project where significant advances were made toward the deliverables described in Section 1.5. The milestones, together with their status, completion date, and corresponding WBE and deliverable, are listed in Table 1.

Table 1: Milestones for ASPIRE project

Milestones	Status	Date	WBEs	Deliverable
1. Sea trial to test Cat. III and Cat. IV REA sampling technologies	Completed	30-Sep-08	1	1
2. Enhancements to the EMM (new data sources, range- and time-dependent modelling)	Completed	31-Dec-11	2	1-3
3. Sea trial to test EMM and PASTET enhancements and reports on these components	Completed	31-Mar-10	1,2	1-3
4. Convert REA database from 'Load' to 'Production' version	Completed	31-May-10	2	1
5. Integration of EMM, PASTET, and READB into System Test Bed (for eventual use and demonstration in PLEIADES)	Completed	31-Mar-12	1-3	2-4
6. Via REP10 sea trial, quantify and report improvements in sonar prediction with varying amounts of REA data assimilation	Terminated	31-Dec-10	1,3	1-4
7. Test sonar prediction performance using REA of varying categories with sea trial data (I, II, IV from Q325, III from REP11)	Completed	31-Oct-11	1,3	1-4
8. Project close-out report	Completed	31-Mar-12		

2 Results

The results of the ASPIRE project broadly consist of the deliverables and outputs described in Section 1.5, including the knowledge and information generated during the project. The results include enhancements to a number of software and modelling systems, particularly the EMM, PASTET, and READB. These results have been captured via a set of thirty reports. In this section, we will give an overview of the results based on the WBE structure of the project. In addition, Section 2.1 describes the objectives and outcomes of the field trial aspect of the ASPIRE project, as the trials included components from more than one WBE. Table 2 summarizes the anticipated outputs of ASPIRE together with the WBEs under which each output fell, and the supporting documentation as numbered in the reference section of this report.

Table 2: Deliverables matrix

Deliverable	WBE	Documentation
1. Demonstration of the capability to collect, exchange, and use the environmental data obtained via Cat. I through IV REA techniques.	1, 2	[7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 1, 3]
2. Demonstration of the capability to integrate sonar performance predictions with an ASW tactical picture.	2, 3	[22, 10, 23, 11, 12, 24]
3. Provision of sonar performance predictions that are based on realistic environmental parameters, for use in calculating zones of influence of naval sonars and for sonar simulations (e.g. multi-statics).	3	[20, 25, 26, 27, 3, 28, 29, 4]
4. Evaluation of the potential to derive environmental products for ASW from MODIS and RADARSAT imagery.	1	[2, 30, 31]
5. Expert advice in the formulation of the statement of requirements for the UWSU/CSC.	3	[32, 33]

2.1 REA Trials

One of the achievements of the ASPIRE project was a set of tests of REA sampling technologies and sonar performance prediction tools with sea trial data. The sea trial experiments were designed to further work being done in each WBE, although the experimental work was primarily done under the auspices of WBE1. Objectives included the development of ground-truthing data and demonstrating systems development as well as concept development. Three CFAV Quest sea trials (Q316, Q325, and Q339A) were scheduled with

a focus on the ASPIRE project. One trial was to be a joint trial with the NATO Undersea Research Centre (NURC - currently CMRE, the Centre for Maritime Research and Experimentation, as of 2012). This trial, Recognized Environmental Picture 2010 (REP10), had to be cancelled due to the unavailability of CFAV Quest, which required major refits. Some of the objectives planned for this trial were shifted to other CFAV Quest trials, and to the REP11 (Recognized Environmental Picture 2011) NURC trial, where experiments were carried out using the RV Alliance as a platform. Finally, some experiments were also performed during the CFAV Quest trial Q343, which was primarily a trial for the Advancing Multistatic Active Sonar Employment (AMASE) Technology Demonstration Project (TDP).

2.1.1 Trial Results Overview

During the course of three CFAV Quest sea trials (Q316, Q325, and Q339A), improvements were made in our ability to handle REA data of Categories I, II, and IV. One significant advance was the development of an improved REA database [15] and later a production version of the database [16] for collecting and accessing data and integrating collected data with acoustic prediction systems. Much of the historical environmental data (Cat. I REA) from DRDC sea trials had been assembled into a modern geospatial database as part of project 11CQ Technology Evaluation for Rapid Environmental Assessment. The new database design facilitated extending the data used for acoustic range prediction from historical data to include remotely sensed and modelled data (from several sources) [14]. It also provided an easy way to store and access data acquired *in situ*, leading to improvements in predictions and estimates of prediction quality. This was demonstrated using data from the Q325 trial [3].

The REA effort of the ASPIRE project also included developing new REA techniques for estimating bottom type from water depth [1] (shown in Fig. 1) and bathymetry from ship radar [8], thus providing an REA technique to obtain bathymetry in shallow water coastal areas. These techniques were discussed at the 2010 NATO Maritime Rapid Environmental Assessment Conference [34, 3]. Both techniques have been compared to data obtained using more conventional methods. The bottom type calculations compare well to the measured data, although some knowledge of the type of sediment deposition processes in the area of interest is probably required. The bathymetry from radar technique compares very well to measured bathymetry, and provides a Category IV REA measurement of bathymetry where charts are unavailable in shallow coastal water where sufficient wave height can be found. The REA sea trials also allowed the collection of ambient noise data for comparison with remotely sensed data, described in Section 2.2.1, and environmental and acoustic data for model comparisons to improve propagation models (Section 2.3.2).

An initial milestone of the project (Section 1.6) included the collection of Category III REA data (as exemplified by glider data) during a collaborative sea trial with the NATO Undersea Research Centre (NURC) involving CFAV Quest, planned for the spring of 2010.

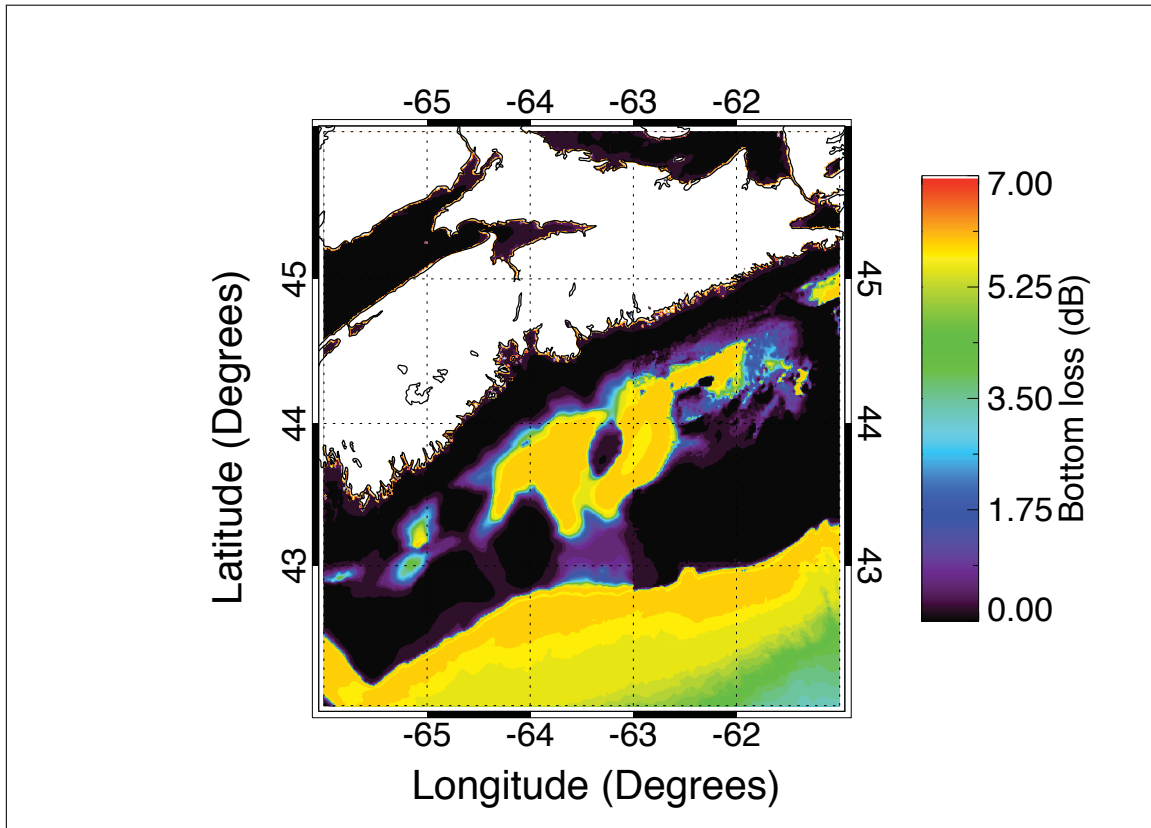


Figure 1: Bottom loss derived from water depth on Scotian Shelf, for 3 degree grazing angle [1].

Due to constraints in ship availability, this trial was cancelled and the milestone terminated. A later joint trial with NURC in 2011 (REP11) however allowed the collection of covert environmental data [7].

2.1.2 Trial Listing

Sea trial Q316

Sea trial Q316, under Chief Scientist John Osler, took place between 8 September 2008 and 19 September 2008. Experiments were conducted in St. Margaret's Bay, Nova Scotia, and on Brown's Bank and in the Northeast Channel, to the south-west of Nova Scotia. In addition, one day of the trial was scheduled for a rapid seabed assessment in the approaches to Halifax Harbour, as support to exercises involving bottoming a Victoria Class submarine.

Q316 included a number of objectives specific to the ASPIRE project. These included demonstrating the use of gliders for the collection of oceanographic and acoustic data in a Category III (covert) REA scenario (WBE 1), measuring acoustic transmission loss and the

ocean environment for tests of the Portable Acoustic Sensitivity Transmission Evaluation Tool (PASTET) (WBE 1 and 3), evaluating an experimental technique relating changes in the wave spectra measured by the ship radar to changes in water depth (WBE 1), and testing interfaces for the Environmental Model Manager (EMM) to ingest historical data from the REA database, from forecast conditions from ocean circulation models (provided by DFO and/or MetOc sources), and from in situ conditions (WBE 1 and 2). In addition to these objectives, there were experiments designed to measure low altitude wind speeds and underwater acoustic noise for comparison with those based on RADARSAT-2 synthetic aperture radar imagery, and to collect ground-truth oceanographic and atmospheric measurements for the Space-borne Ocean Intelligence Network (SOIN) initiative. These experimental objectives also furthered the ASPIRE project. Finally, a number of engineering tests of equipment used in the ASPIRE project were planned, most notably of modifications to the hardware and software that enable rapid seabed assessment using the Moving Vessel Profiler (MVP) and Free Fall Cone Penetrometer (FFCPT).

Most of the Q316 objectives were successful. The results are discussed in the following sections. The one unsuccessful objective was a deployment of the gliders for collecting Category III REA data. Due to personnel issues, this objective was deferred to the REP10 trial, and then to the REP11 trial when the REP10 trial did not proceed. Even without the glider data, a significant amount of oceanographic and acoustic data was collected for analysis and for comparison to acoustic propagation model results.

Sea trial Q325

Sea trial Q325 took place between 26 October 2009 and 20 November 2009. The trial Chief Scientist was Sean Pecknold. The primary experimental locations were on the Scotian Shelf, in and around the Emerald Basin, Sambro Bank, and Emerald Bank areas. Some tests were also conducted in the Bedford Basin and St. Margaret's Bay. Most of the trial objectives were related to the ASPIRE project. These included measuring acoustic transmission loss and comparing its spatial and temporal variability/uncertainty with predictions from PASTET (WBE 1); developing and testing interfaces for the Environmental Model Manager to ingest historical data from the READB, forecast conditions from ocean circulation models (provided by DFO and MetOc sources) and in situ conditions (from glider, MVP, and XBT measurements) (WBE 1, 2, and 3); and tests of equipment used for ASPIRE, including the MVP, FFCPT, and various acoustic projectors and recorders.

Sea trial Q325 was a successful sea trial. Most of the trial objectives were met, with one experiment (not an objective of the ASPIRE project) having to be curtailed as problems with the ship's radar shortened the trial duration. In addition to the data collected for acoustic transmission loss, oceanographic and geoacoustic parameters, and in-air acoustics, a significant number of systems required for the experimental work undertaken in ASPIRE were tested, leading to improvements in software and hardware.

Sea trial Q339A

Sea trial Q339A was an engineering trial, primarily designed to test improvements to equipment based on the results of the previous ASPIRE trials. The trial took place between 20 June 2011 and 8 July 2011, in the Emerald Basin on the Scotian Shelf. The Chief Scientist was Jeff Scrutton. Although most of the objectives were related to testing the performance of acoustic and oceanographic equipment, data was acquired in support of the ASPIRE project as well, and used for testing improvements made to the EMM and PASTET software packages.

Sea trial REP11

The Recognized Environmental Picture 2011 (REP11) trial, under Chief Scientist Kyle Becker of NURC, took place in the Gulf of Taranto, in the northwest Ionian Sea. The trial consisted of two legs. The first leg, REP11A, took place from 13-24 August 2011. Its focus was on oceanographic measurements and modelling. The second leg, REP11B, took place 26 September - 16 October 2011. Participants from DRDC Atlantic, under Sean Pecknold, took part in the second leg, which included acoustic measurements along with the oceanographic measurements.

The trial was in support of the Environmental Knowledge and Operational Effectiveness (EKOE) program outlined in the NURC Consolidated Programme of Work 2011. This program seeks to integrate environmental knowledge, including uncertainty, with decision support tools designed to assess operational impact and risk. The overall trial objectives were twofold:

1. Environmental Characterization

- Collect temperature and salinity (TS) data as a function of time and space in the operational area in a persistent manner using a combination of fixed and mobile assets to compare with models. Data will be collected using moorings, gliders, and ship deployed systems (CTD, Scanfish, CTD chain). Data will at first be collected and used to initialize ocean forecasting models. Subsequent data will be used to update models and also validate 1, 2, 3 day forecasts by re-sampling specified areas. Goal is to obtain statistics of TS field and resulting sound speed field both temporally and spatially.
- Collect optical data from profilers and water samples to support development of optical inverse methods.
- Collect wave height data from wave-height buoy and radar for comparison/ calibration of wave-heights obtained from specially instrumented glider.
- Path prediction modeling with uncertainty along with risk assessment will be incorporated into glider mission planning.

- In addition, satellite SST data will be acquired and integrated into ocean forecast models.

2. Acoustics

- Collect acoustic Transmission Loss (TL) data over pre-defined tracks and geometries in a persistent manner using a combination of fixed and mobile assets. Primary receiver will be a 31 element 75 m aperture Vertical Line Array (VLA). Goal is to obtain temporal and spatial statistics of acoustic quantities to compare with the corresponding uncertainties estimated through propagation modelling. A further goal is to compare measured acoustic data with acoustic model outputs as they might be used for decision making.
- Estimate relative level of spatial variability in seafloor impedance from seismic reflection measurements.

The DRDC component of the trial included both environmental characterization via a fixed CTD mooring, and acoustic measurements using DRDC acoustic recorders and projector. These measurements, and the measurements acquired using the NURC equipment, contributed to WBE 1 and 3 of the ASPIRE project.

Sea trial Q343

Sea trial Q343, under Chief Scientist Brian Maranda, occurred in the Gulf of Mexico from 9 to 28 January, 2012. The trial was intended primarily for tests of equipment and initial concepts for the AMASE TDP, but it also provided an opportunity for collection of environmental and acoustic data for ASPIRE. Improvements to the way EMM and PASTET processed XBT and ocean forecast data were tested, and minor code fixes were implemented to address some problems that were found.

2.2 WBE 1: Optimal Sampling of the Underwater Environment

Work undertaken in WBE 1 concentrated on how best to characterize the underwater environment. This characterization included measurement and estimation techniques such as the experimental work and the development of new techniques described in Section 2.1. Work done in conjunction with SOIN on remote sensing and sonar parameters (Section 2.2.1) also fell within WBE 1. A great deal of work was accomplished within ASPIRE on the sensitivity of sonar performance predictions to environmental variability and uncertainty, as well. This work, described in Section 2.2.2, fell within both WBE 1 and WBE2.

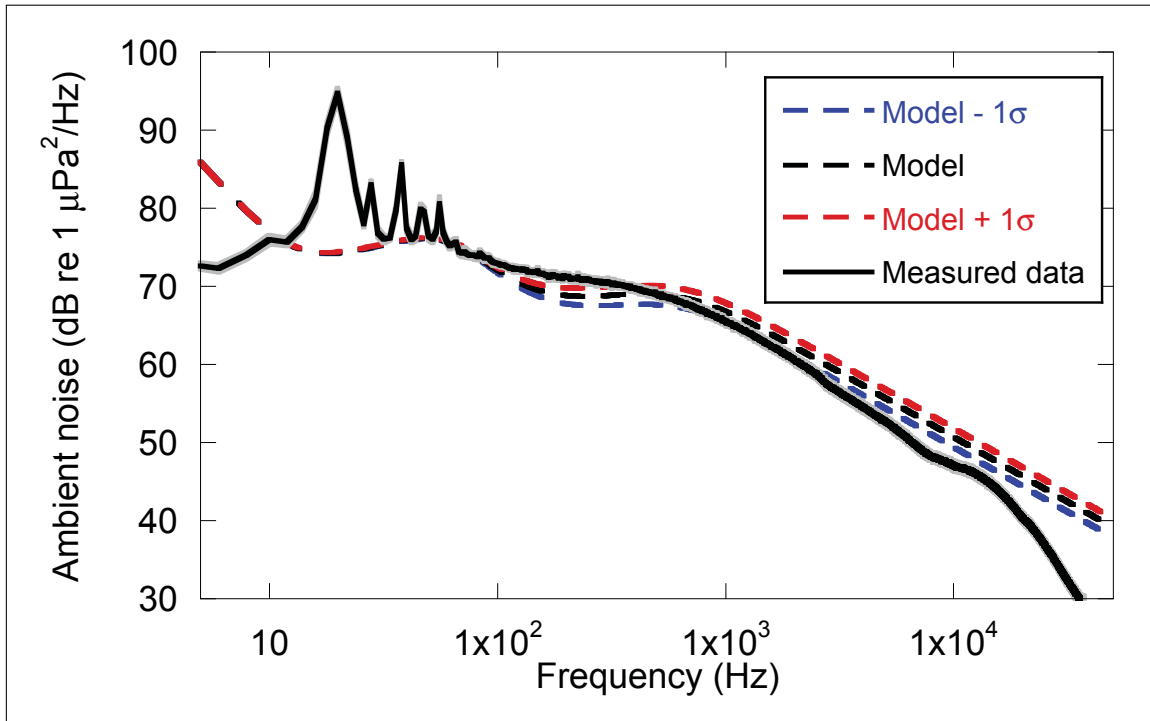


Figure 2: Measured and modelled ambient noise power spectral level for 31 October 2009. The black line shows the mean measured ambient noise level, with the gray lines showing one standard deviation [2].

2.2.1 Remote Sensing and Sonar Parameters

Remotely sensed data generally falls into Categories II or III of REA, and can be an important input for the Recognized Environmental Picture. The question of how to estimate sonar environmental parameters from remotely sensed data was addressed in conjunction with the Spaceborne Ocean Intelligence Network (SOIN) project [31]. SOIN is a six-year research and operational development initiative, begun in 2007, and is designed to improve the exploitation of space-based Earth observation sensors, Radarsat in particular, for oceanographic products. The initiative is funded by the Canadian Space Agency (CSA) and partners a number of governmental departments, agencies, and operational CF units with other organizations, such as Dalhousie University and the US Naval Research Laboratory (NRL) Stennis. DRDC Ottawa has developed algorithms to calculate wind speed from Radarsat imagery. As part of ASPIRE, these Radarsat-derived wind speeds were used to generate modelled ambient noise levels and surface reverberation and loss levels, and these were then compared to measurements made during sea trials. The results were documented in a TTCP technical report and in the scientific literature [2, 28]. An example of measured ambient noise acquired during one of the ASPIRE sea trials compared to modelled ambient noise based on remotely sensed wind speeds is shown in Fig. 2.

2.2.2 Sensitivity Analysis

A major part of ASPIRE was developing a way to estimate both how to sample the environment to obtain better sonar performance predictions, and how to quantify the uncertainty in performance due to the environment. A software tool was developed to quantify how environmental uncertainty affects propagation, the Portable Acoustic Sensitivity and Transmission Estimation Tool (PASTET) [13]. This tool was used to estimate transmission loss (TL) and the sensitivity of transmission loss predictions to variability and uncertainty in the environment during the course of the ASPIRE sea trials [12] (Section 2.1). An example of the PASTET computations is shown in Fig. 3, using category II REA data with multibeam bathymetry from the Canadian Hydrographic Survey (CHS) and sound speed profiles (SSP) from the U.S. Naval Coastal Ocean Model (NCOM). The sensitivity measure shows the relative change in acoustic pressure measured at a given range and depth (given a source at 52 m depth) for a characteristic (one standard deviation) fluctuation in the environment (in this case, bottom compressional sound speed, sound speed profile, or bathymetry). This example is for an area in the Emerald Basin, on the Scotian Shelf (in MARLANT Ope Area G2).

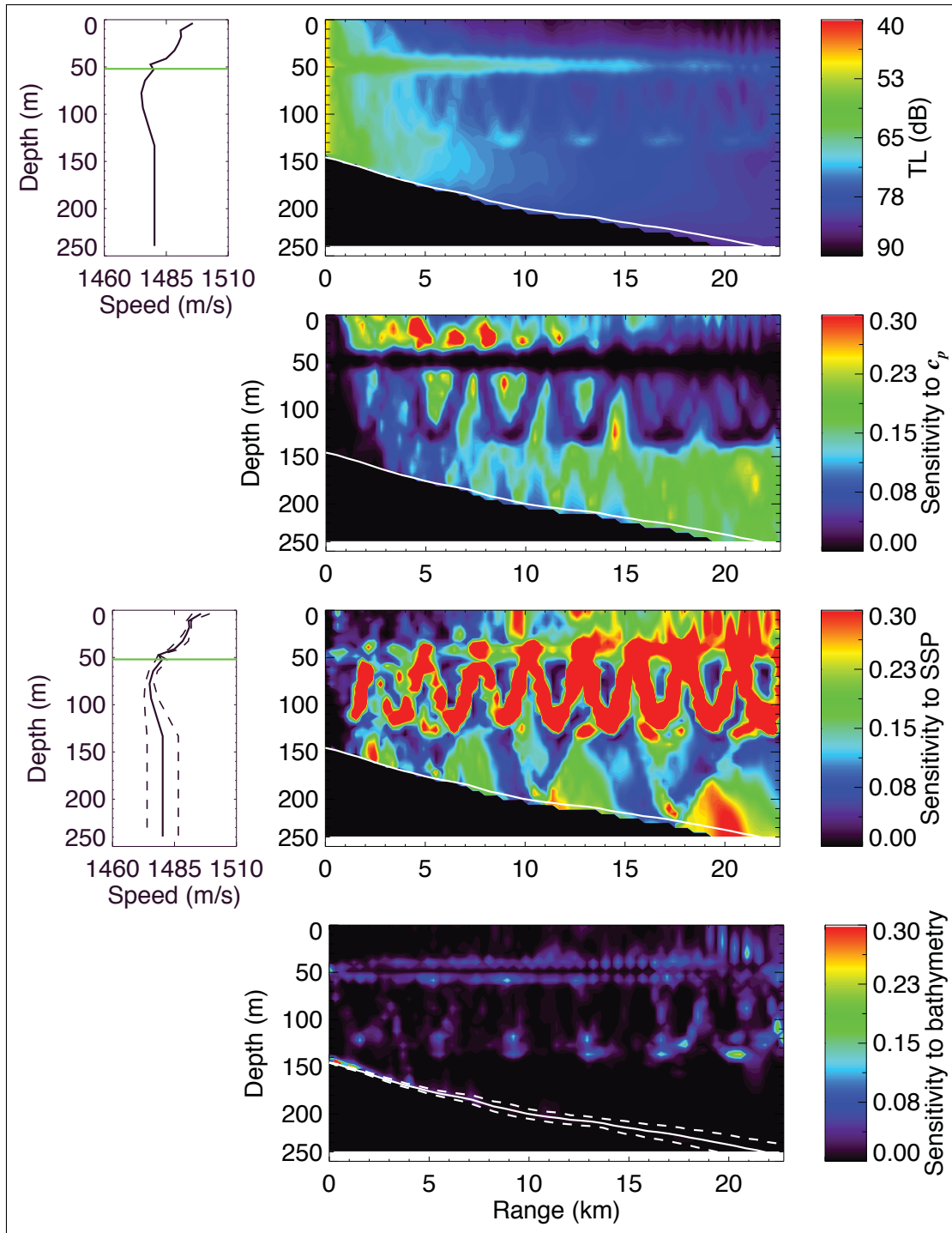


Figure 3: REA Cat. II transmission loss and sensitivity fields for bottom compressional sound speed c_p , SSP using the NCOM model, and CHS bathymetry[3]. The left hand column shows the mean SSP and the one-standard deviation change in SSP from the model for the area. Mean and standard deviations for c_p are 1499 m/s and 30 m/s, computed from the water depth [1]. Source is at 52 m depth.

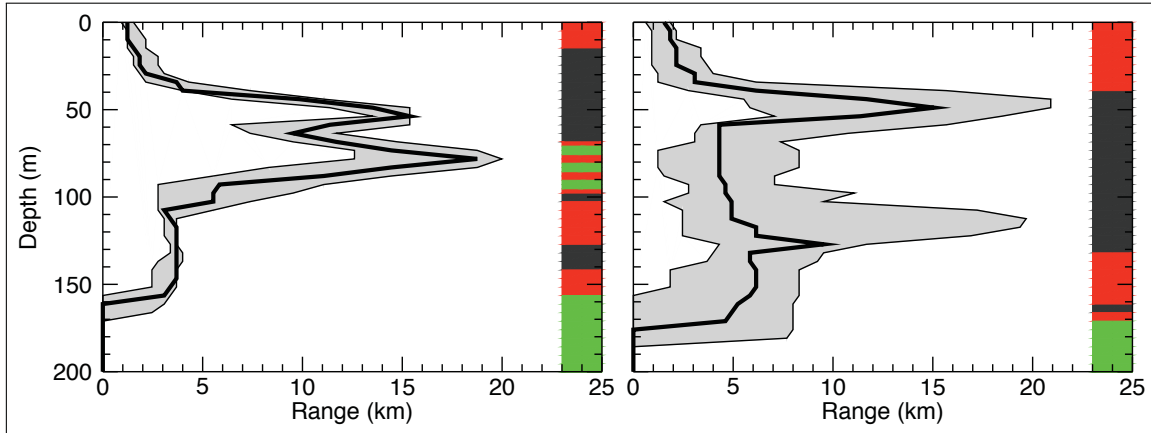


Figure 4: Expected range for less than 70 dB TL (black lines), with minimum and maximum based on environmental uncertainty (grey), and dominant sensitivity component vs. depth on right side using colour code (red is c_p , green is bathymetry, dark grey is SSP derived from Cat II (C-NOOFS) (left), Cat II (NCOM) (right). Source is at 52 m depth[3].

PASTET was used to analyze the data collected from previous sea trials (as documented in [3]). Integration of sensitivity measures into the tactical ASW picture has been advanced by incorporating the PASTET program into the Environmental Model Manager (EMM), a component of the System Test Bed [10, 9, 11]. PASTET was also used for calculating the uncertainties in sonar performance predictions made using different sources of REA data, showing improved acoustic range prediction with increasing REA classes. An alternative way of displaying the transmission loss and sensitivity information was developed that provides a visualization of how the environmental uncertainty impacts performance prediction. Using computations from PASTET and considering a dipping sonar or towed array, we can calculate the expected, maximum, and minimum likely ranges for a given level of signal excess with respect to depth. For example, in Fig. 4 we assume a source at 52 m depth and compute the range at which the TL is less than 70 dB, as a function of receiver depth. To the right of each plot the parameter to which the propagation is most sensitive at that range and depth is designated by colour coding. Thus Fig. 4 shows expected range to a 70 dB transmission loss (or equivalent signal excess given defined system parameters) at different depths, together with the uncertainty in those ranges based on environmental uncertainty, for two different sources of REA data, the C-NOOFS (Canada-Newfoundland Ocean Observation and Forecasting System) and NCOM ocean models, respectively. Figure 4 also shows the dominant driver of the propagation uncertainty at each depth, providing an indication of what measurements would be required to reduce uncertainty in range prediction.

2.3 WBE 2: Environmental Model Manager+

2.3.1 Rapid Environmental Assessment Database

An important element in WBE 2 was addressing the requirements for data storage and exchange for large streams of diverse environmental data. A prototype database (the READB) had been developed for storing existing environmental data generated by DRDC Atlantic. This database was improved to allow for *in situ* and remotely sensed data sources, and to more easily use the data stored within the READB for acoustic modelling [14]. To better serve the requirements of scalability, flexibility, and data exchange, a new data model design was decided upon and documented [15]. The new READB model uses the Arc Marine model for the data and components of the International Organization for Standardization (ISO) 19115 standard for the geospatial metadata. Based on these common standards and specifications, the READB now allows improved interoperability with other environmental databases, such as those used by the DND Meteorological and Oceanographic (MetOc) Office and Department of Fisheries and Oceans sections. The data model was tested by porting the existing environmental data from the original READB to the new Production Database (PDB) [16], which was then used during the Q343 sea trial, as described in Section 2.1. The developed data model can now be transferred to an operational system and integrated with models that deliver REA operational products to deployed forces [15].

2.3.2 EMM Enhancements

The Environmental Model Manager (EMM) is a module of the System Test Bed (STB) experimental platform that is used as the basis for the PLEIADES signal processing, tactical plot and display system. This system has been tested on several sea trials on CFAV Quest and Halifax Class Frigates. EMM, which was originally developed for project 11CG, Networked Underwater Warfare TDP, is the module that runs acoustic range predictions based on data from the ship systems. EMM obtains environmental information from databases or *in situ* data for input into an acoustic propagation model (Bellhop), and has a service oriented architecture. EMM runs environmental analyses based on real-time own and other platform information and allows the results of these analyses to be displayed on the STB tactical plot. The architecture of EMM and its integration with the STB tactical plots and signal processing make it a useful framework for the development of research tools. The STB also provides a framework (the PLEIADES system) that allows technology such as the EMM and the algorithms and models integrated into it to be tested on non-research platforms such as RCN ships.

Much of the work undertaken in WBE 2 involved integration, in particular tying the PASTET software package into the EMM. This work [10, 9] is described in Section 2.2.2. Other elements of EMM development involved improvements to the core models of EMM, described in Section 2.4. Finally, some work was done in conjunction with the 11CB 'Automated Clutter Discrimination using Aural Cues' project on integrating a very fast adia-

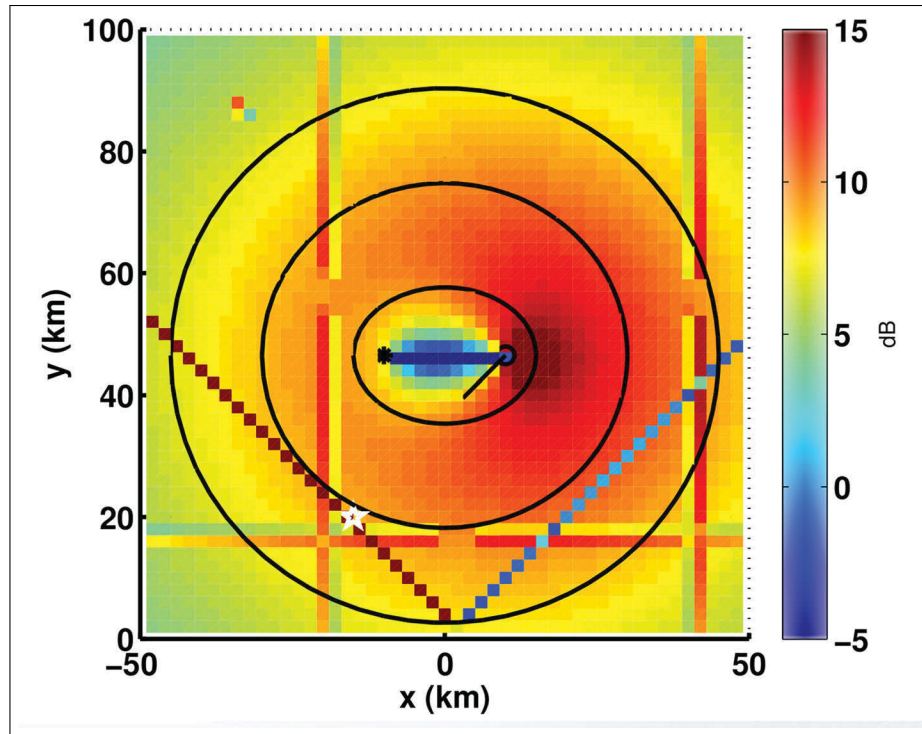


Figure 5: Modelled signal excess for a bistatic reverberation example from [4], using range dependent environments, target strengths, and scattering strengths. Black bar indicates the steering angle of the towed-array receiver.

batic normal modes propagation model [4] into the EMM [24]. This was done to provide an alternative active sonar propagation and reverberation model for use with the ASPIRE and Clutter projects. Fig. 5 shows an example of bistatic signal excess calculations made on a 100x100 km grid using the clutter model. The figure shows the main features of the model. It can have range dependent bathymetry (and potentially sound speed profile and bottom properties). Here, the water depth is 100 m, except for two ridges in the y -direction rising to 60 m, and another ridge rising to 70 m in the x -direction; all ridges have gaps near the middle. There is also a seamount of height 50 m in the northwest quadrant. Lambert scattering was used to calculate the bottom reverberation, using a scattering strength of -27 dB, except for a +10 dB enhancement along the line (2,2) to (50,50). The 10 m deep target is assumed to have an echo strength of 8 dB (17 dB along the line (-48,52) to (2,2), to show that the model can use a variable and potentially aspect-dependent target strength). The source is at (-10,48) at depth of 30 m, and the receiver, a towed array with steering angle 225 deg, is at (10,48) at a depth of 50 m.

2.4 WBE 3: Sonar Performance Prediction Using Realistic Environments

WBE 3 was designed to provide sonar performance predictions that are integrated with the ASW tactical picture. The tool chosen to do this was the EMM, due to its integration with the STB and PLEIADES, as described in Section 2.3.2. A number of enhancements were made to EMM as part of WBE 2 and WBE 3 of ASPIRE. Improvements were made to the Bellhop acoustic propagation model that is the core acoustic propagation model of the EMM [27, 20, 17, 21, 26, 29]. These improvements included the capability to use more complex and realistic environments, in particular for the bottom, and the ability to more accurately represent the actual environment while still acting with the efficiency required of a real-time model. The improvements were validated with comparisons to measured acoustic data acquired during the ASPIRE sea trials. The Bellhop model, originally designed for passive sonar work, was also extended to handle active sonar [25, 18]. Integration of these active components into the EMM provided an initial active sonar performance prediction capability [23], which calculates active signal excess and probability of detection for monostatic sonar. An example of the tactical chart and active signal excess output from the STB is shown in Fig. 6. A capability for calculation of zones of influence (ZoI) on marine mammals was also added to the EMM, in conjunction with Project 11CA, Enabling CF Multistatic Sonar.

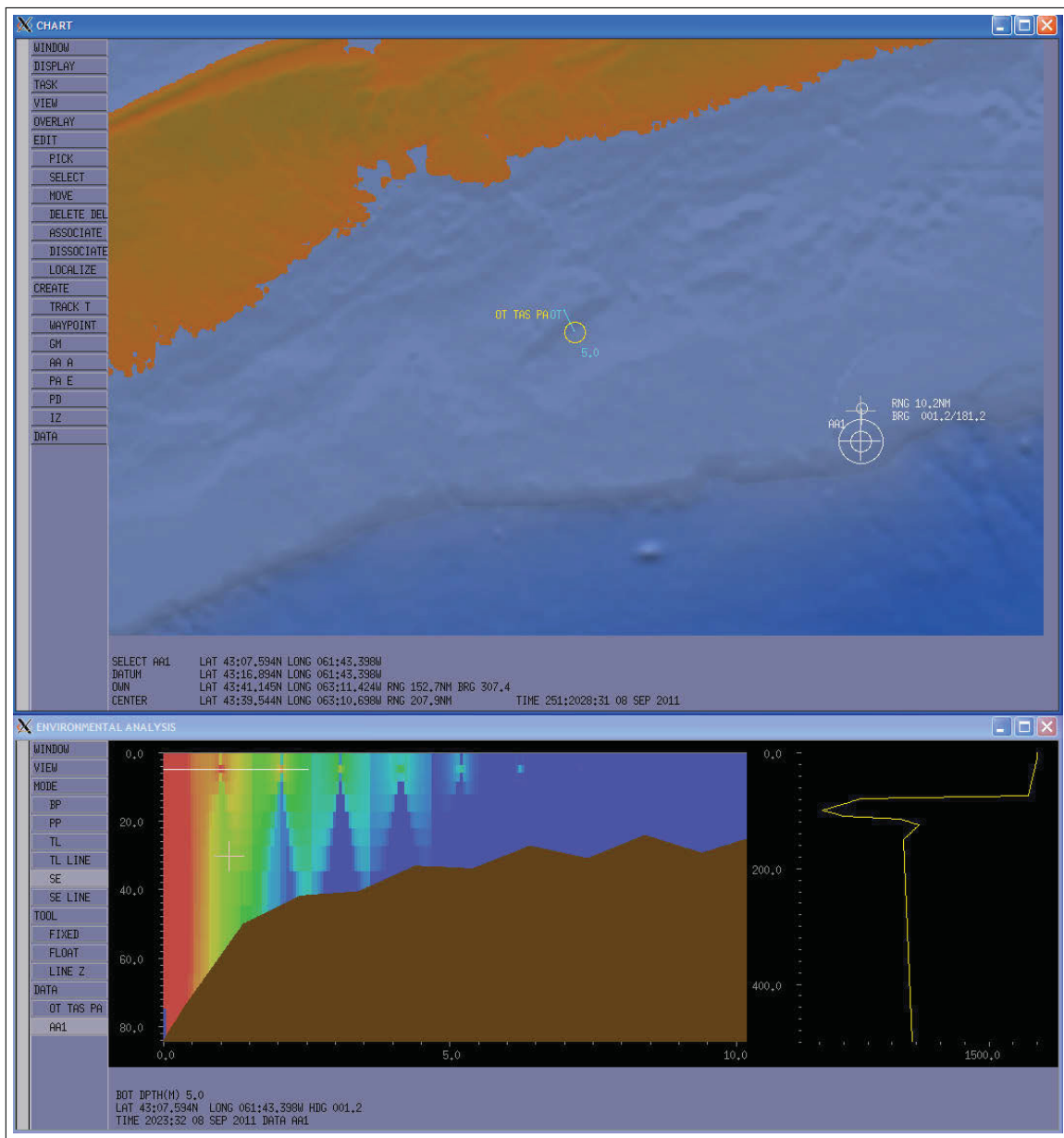


Figure 6: The CHART (top) and ENVIRONMENTAL ANALYSIS (bottom) windows of the STB showing active signal excess (SE) along a 10.2 nm, 001 degree line of bearing.

3 Further Work

Each of the ASPIRE work breakdown elements can be progressed. Further work can be done on the EMM integration. The current operational acoustic range prediction systems (ARPS) do not provide guidance as to where additional sampling is needed. They cannot use near real-time forecasts output from ocean circulation models, and they cannot indicate where the uncertainty in the performance prediction is worst because of uncertainty or variability in the environmental parameters. These capabilities are now available within EMM and are well-integrated with the tactical picture. Improvements in how the new information is displayed and used in the tactical picture could be developed.

More research is also needed into the sensitivity measures developed in this project. Towards the end of ASPIRE, extensions of the sensitivity and optimal sampling work were made to the active version of Bellhop [19], but the requirements for transforming these measures into a tactical decision aid (TDA) are not well defined. An extension to multistatic active sonar is also required, tying in to the requirements of the Advancing Multistatic Active Sonar Employment (AMASE) TDP. Multistatic sonar performance prediction is now possible using the active Bellhop model, but the results and performance of this model can be compared to the normal modes model used in the DRDC Clutter Model, that was developed in conjunction with the 11CB project (Automatic Clutter Discrimination Using Aural Cues).

Finally, the applicability of these tools can be extended in a number of ways. This includes implementing optimal and adaptive sampling techniques for multistatic or continuous active sonar; and extending our current REA and performance prediction capabilities to more complex or less well-understood environments, such as the Arctic.

4 Conclusions

The ASPIRE project achieved its intended outcomes. Collection, exchange, and use of environmental data obtained via Cat. I through IV REA techniques was demonstrated; sonar performance predictions were integrated with an ASW tactical picture; a capability to provide sonar performance predictions based on realistic environmental parameters was developed within the EMM; the potential to derive environmental products for ASW from MODIS and RADARSAT imagery was evaluated; and expert advice was provided for the formulation of the statement of requirements for the Canadian Surface Combatant. Remote sensing and ocean forecast models were incorporated into EMM, as were marine mammal zone of influence calculations and an active sonar range prediction capability. Additionally, the PASTET tool, designed to identify the key parameters governing acoustic propagation and quantify the uncertainty in sonar performance due to uncertainty or variability in environmental information, was integrated with the EMM. Future work will adapt and extend the capabilities developed through the ASPIRE project in new areas to improve performance prediction for underwater sensing and communications.

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Annex A: Project Linkages

The ASPIRE project was principally undertaken by the Underwater Sensing (US) Section at DRDC Atlantic with the support and participation of the Maritime Information and Combat Systems (MICS), the Technology Demonstration (TD), and Technical Services (TS) sections. The project linked to several DRDC projects:

- 11CA: 'Enabling CF Multistatic Sonar' and 11CM: 'Advancing Multistatic Active Sonar Employment' for multi-static sonar performance and mitigating the impact of naval sonar on marine mammals
- 11CB: 'Automated Clutter Discrimination using Aural Cues' for the integration of environmental information (bathymetry) and sonar conditions (reverberation) into PLEAIDES
- 11HL: 'Technologies for Trusted Maritime Operational Awareness' for the development of the architecture for the recognized environmental picture
- 11BW: 'Victoria Class C3 Optimization' for the high level architecture for synthetic environment simulations
- 20EA05: 'Support to CMS: Ruggedized Sonar Test System' for integration into the PLEAIDES system

External to DRDC, the project contributed to an inter-departmental effort, led by the Department of National Defence and funded by Canadian Space Agency, entitled the 'Space-borne Ocean Intelligence Network (SOIN)'. SOIN provides a coordinated, and therefore cost-effective, approach to producing and distributing MetOc products in operational time frames and formats using space-borne remote sensing in littoral, coastal, and oceanic waters. DRDC Ottawa was also involved with the extraction of maritime environmental information from MODIS and Radarsat imagery through SOIN.

ASPIRE collaborated with the U.S. Naval Research Laboratory, Dalhousie University, and the Department of Fisheries and Oceans in the field of numerical models to provide forecasts of ocean sound speed structure (based on modeled temperature and salinity) will be investigated. Internationally, the project collaborated with a new Key Technical Area in TTCP TP-13 entitled Environmental Battlespace Characterization and with research being undertaken in the Command and Operational Support and Expeditionary Operations Support Thrust areas at the NATO Undersea Research Centre.

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Annex B: List of Abbreviations

AMASE	Advancing Multistatic Active Sonar Employment
ARP	Applied Research Project
ARPS	Acoustic Range Prediction System
ASPIRE	Assessing Sonar Performance in Realistic Environments
ASW	Anti-submarine warfare
CHS	Canadian Hydrographic Service
CMRE	Centre for Maritime Research and Experimentation
C-NOOFS	Canada-Newfoundland Ocean Observation and Forecasting System
DFO	Department of Fisheries and Oceans
DRDC	Defence Research and Development Canada
EMM	Environmental Model Manager
NATO	North Atlantic Treaty Organization
NCOM	Naval Coastal Ocean Model
NURC	NATO Undersea Research Centre
PASTET	Portable Acoustic Sensitivity and Transmission Estimation Tool
R & D	Research and Development
RCN	Royal Canadian Navy
REA	Rapid Environmental Assessment
REP	Recognized Environmental Picture
SOIN	Spaceborne Ocean Intelligence Network
SSP	Sound speed profiles
STB	System Test Bed
TDP	Technology Demonstrator Project
TRL	Technology Readiness Level
TTCP	The Technical Cooperation Panel
WBE	Work Breakdown Element
ZoI	Zones of Influence

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The Assessing Sonar Performance in Realistic Environments (ASPIRE) project, completed in March 2012, was a four year Applied Research Project that was intended to determine how to sample the underwater environment in an adaptive and optimal manner to enhance tactical decision making for anti-submarine warfare (ASW). The project achieved its proposed outcomes, developing and improving tools for identifying what aspects of the environment limit our ability to accurately predict sonar performance, and how to best sample the environment to minimize these limitations. The project also demonstrated our capability for using Rapid Environmental Assessment (REA) techniques to optimize our predictions and sonar performance, and showed how REA-derived products and predictions can be integrated with the ASW tactical picture.

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Rapid Environmental Assessment
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